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A Study of Mandatory Engine Maintenance for Reducing Vehicle Exhaust Emissions

executive summary

Vol. 1

TRW Systems Group

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A Study of Mandatory Engine Maintenance for Reducing Vehicle Exhaust Emissions

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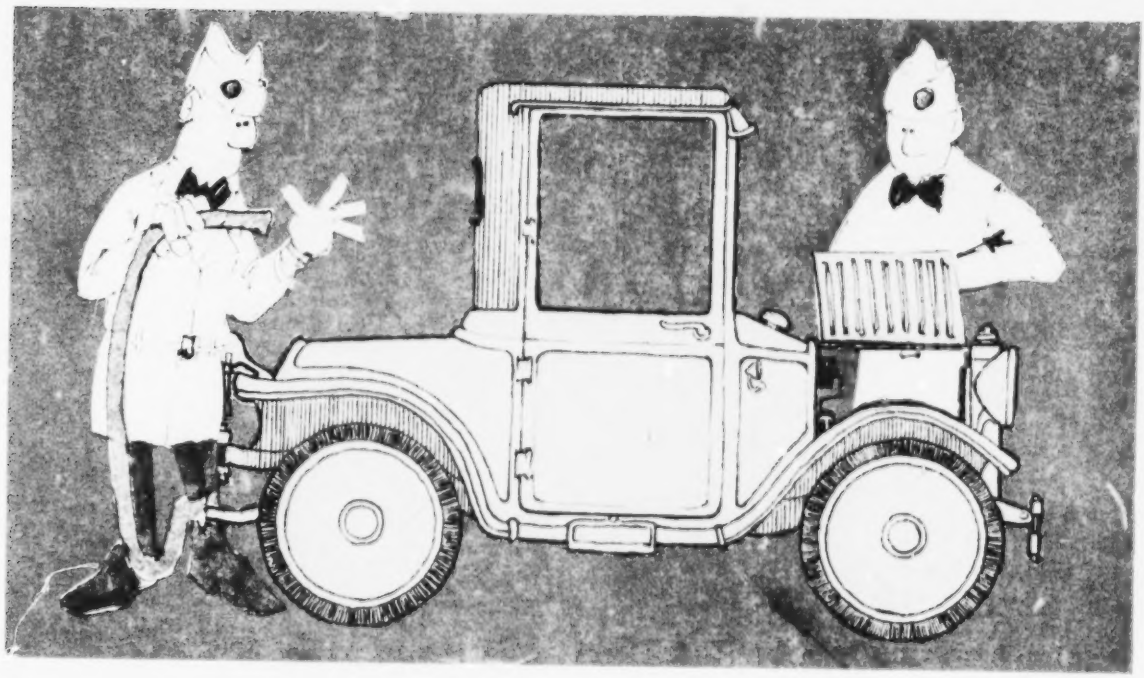
Volume I. Executive Summary



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16. Abstracts

This volume summarizes the general objectives, approach and results of the study. The economic effectiveness model is designed to evaluate two general vehicle inspection and maintenance strategies: (1) direct inspection of engine and control device adjustments and their maintenance using conventional or more sophisticated garage equpment and (2) measurement of exhaust emissions at various engine loads to diagnose engine maladjustments followed by their subsequent maintenance. The model provides considerable latitude to investigate particular procedures within the framework of these two general strategies.

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PREFACE

This report, "A Study of Mandatory Engine Maintenance for Reducing Vehicle Exhaust Emissions," consists of six volumes. The following are the subtitles given for each volume:

- Executive Summary, Volume I
- Mandatory Inspection/Maintenance Systems Study, Volume II
- A Documentation Handbook for the Economic Effectiveness Model, Volume III
- Experimental Characterization of Vehicle Emissions and Maintenance States, Volume IV
- Experimental Characterization of Service Organization Maintenance Performance, Volume V
- A Comparison of Oxides of Nitrogen Measurements Made With Chemiluminescent and Non-Dispersive Radiation Analyzers, Volume VI.

The first volume summarizes the general objectives, approach and results of the study. The second volume presents the results of the mandatory inspection/maintenance system study conducted with a computerized system model which is described in Volume III. The experimental programs conducted to develop input data for the model are described in Volume IV (Interim Report of 1971-72 Test Effort) and V. Volume VI presents comparative measurements of NO and NO_x using chemiluminescence and NDIR/NDUV instruments and differences in these measurements are examined.

The work presented herein is the product of a joint effort by TRW Systems Group and its subcontractor, Scott Research Laboratories. TRW, as the prime contractor, was responsible for overall program management, experimental design, data management and analysis, and the economic effectiveness study. Scott acquired and tested all of the study vehicles. Scott also provided technical assistance in selecting emission test procedures and in evaluating the test results.

A STUDY OF MANDATORY ENGINE MAINTENANCE PROCEDURES
FOR REDUCING VEHICLE EXHAUST EMISSIONS

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1.0 INTRODUCTION

This report of the Study of Mandatory Engine Maintenance for Reducing Vehicle Emissions summarizes results obtained during the first year of the Extended Phase One Emission Test Program. The main objective of this work was to assess the feasibility of reducing exhaust emissions through mandatory vehicle inspection and maintenance. The Extended Phase One effort involved the following activities:

1) Testing of 450 privately owned vehicles to measure both emission and engine adjustment deterioration rates over five four-month intervals. Of the five test periods, two are complete.

2) Testing of 16 pre 1966 and post 1970 vehicles to establish specific relationships between engine settings or adjustments and exhaust emissions. (These relationships were developed for 1966-1970 vehicles during the previous program.)

3) Testing of 260 privately owned vehicles in the Detroit area to compare their frequency and extent of engine maladjustments with results previously obtained in the Los Angeles area.

4) Evaluation of the effectiveness with which service organizations maintain a selected class of engine malfunctions and maladjustments.

5) Upgrading the Economic Effectiveness Model and using it to evaluate proposed inspection/maintenance procedures.

Items 2) through 5) have been completed. The remaining work is the completion of the engine deterioration tests, the final updating of the Economic Effectiveness Model using the new test data, and the selection of preferred inspection/maintenance procedures based on the completed test series and the updated model. The results obtained to date are reported in detail in Volumes II through VI. The material of these reports forms an essential background for any state or regional air pollution agency considering mandatory inspection/maintenance to meet the new Federal ambient air quality standards.

The conclusions of the Extended Phase One Program tend to reinforce those given in the Interim Report in January 1972, but are based upon a broader data base which includes:

- a more representative vehicle population including pre 1966 vehicles which are not emission controlled, 1966-1970 emission controlled vehicles and 1971 NO_x controlled vehicles (State of California)
- experimental data on repair effectiveness and maintenance deterioration rates
- all emission predictions based upon 1972 Federal Emission Test Procedures.

The difficulty of achieving positive correction of faulty engine adjustments became apparent in the current phase as a result of studying repair effectiveness. The more promising results of the Interim Report were based on the assumption of "perfect maintenance", which is clearly optimistic. Nonetheless, there are definite indications that significant emission reductions can be achieved, particularly in the pre 1971 vehicles, through an emissions inspection followed by corrective maintenance. The best strategy is strongly dependent on the regional objectives and the consequent importance assigned to the reduction of each emission specie.

Because of the nature of automotive emissions measurements and control (including legislation, equipment design and inspection/maintenance criteria), it is strongly recommended that any proposed mandatory maintenance program be tested on a pilot basis before it is widely instituted.

2.0 APPROACH

This continuing study is being performed in three parts: development of mathematical models and analytical methods; acquisition of experimental data to support the analytical effort; and evaluation of proposed inspection/maintenance strategies to determine an optimal policy. These three major activities are described briefly in this section. For further detail the reader is directed to the relevent volume of this six volume report.

2.1 ANALYTICAL METHODS

The major analytical activities involve simulation of inspection and maintenance processes, optimization of procedures and studying the sensitivity of results to uncertainties in both the data base and assumptions.

Simulation

The simulation activity involves formulating a conceptual model of inspection/maintenance procedures. The major elements of this model describe the inspection/maintenance process, facility configurations, and capital and operating costs. A figure of merit is calculated to compare the cost and performance effectiveness of selected inspection and maintenance policies. This Economic Effectiveness Model, written in Fortran IV for the CDC 6500, accepts empirical data obtained from the experimental program to provide realistic procedure effectiveness evaluations.

Optimization

This phase involves optimization of inspection/maintenance strategies on the basis of cost, weighted [1] emission reduction, or cost effectiveness. The latter measure is simply the ratio of the first two. The optimization procedure uses a linear programming algorithm to select initial values for the pass/fail criteria to be used for vehicle inspection. These cutpoints are then progressively refined until an optimal rejection rate for the region is achieved. In addition to determining the best

(1) Species weights are selected in accordance with regional objectives. For the Los Angeles area, where photochemical smog is the main problem, the weights are HC, 0.6; CO, 0.1; NO_x, 0.3.

pass/fail criteria for the region, a comparison is made of the effectiveness of inspection in state lanes and franchised garages, different levels of inspection and maintenance are evaluated and the best inspection interval identified. These factors combine to form a statement of preferred inspection and maintenance policy.

Sensitivity Analysis

The final step in the analysis procedure is to assess the validity of results by studying their sensitivity to data and assumptions used in the model. The consequences of variations in the following quantities are examined:

- effects of voluntary maintenance
- maintenance effectiveness
- pass/fail criteria
- inspection interval
- number of lanes per station
- deterioration rates of engine settings
- species weight factors
- rejection rates
- emission deterioration rates
- labor rates

The Economic Effectiveness Model is being developed as a research and design tool which can be used to assess mandatory vehicle inspection and maintenance as a means of reducing exhaust emissions.

2.2 EXPERIMENTAL PROGRAM PLAN

The experimental program involved four major tests:

- A periodic survey of a large fleet of vehicles in the Los Angeles area to measure the rate with which engine adjustments and corresponding exhaust emissions deteriorate with vehicle use.

- Tests of 16 vehicles to relate engine adjustments to exhaust emission levels.

- A survey of 260 privately owned vehicles in the Detroit area to establish the frequency and extent of malfunctions and maladjustments in vehicles in this region.

- Evaluation of garage maintenance effectiveness.

Engine Adjustment and Exhaust Emission Deterioration Tests

Three groups of 150 privately owned vehicles were acquired for these tests consisting of pre-1966 automobiles which are not exhaust emission controlled, 1966-1970 vehicles which have hydrocarbon and carbon monoxide controls and 1970 vehicles which are also NOX controlled. The vehicle mix within each fleet is typical of the vehicle population in the Los Angeles area.

In this continuing experiment both exhaust emissions and engine adjustments are measured in each vehicle at approximately four month intervals. The tests are designed to obtain statistically significant deterioration data for engine adjustments as well as exhaust emissions. The vehicles were first subjected to comprehensive inspection and repair. The following items were checked: spark plugs, coil, points, dwell, condenser, timing, spark advance (total, mechanical and vacuum), idle RPM, idle fuel to air ratio, manifold vacuum, air cleaner, float level, choke vacuum kick, NO_x control device, PCV valve and air pump. Critical components were tested and emission measurements made. Parts were replaced as necessary and the engine tuned to manufacturer's specifications. Emission measurements were repeated after "initialization" maintenance to provide a "baseline" for the deterioration experiment. The emission tests included cold start tests using the 1972 Federal Test Procedure as well as hot start emission tests performed under idle as well as loaded engine operating modes. Constant volume sample (CVS) emission measurements and direct concentration measurements were made.

Test to Relate Engine Adjustments to Exhaust Emissions

These tests were performed to establish the relationship between engine adjustments and exhaust emissions and to provide data with which to predict emission concentrations resulting from malfunctions or maladjustments. Sixteen vehicles were tested. Half were of the pre-control

type (pre 1966 vehicles) and half had NO_x control devices (1971 vehicles). Each group was selected to represent the principle classes of vehicle makes, engine options and drive trains. Previous experiments had identified five engine maladjustments and malfunctions having a large influence on emissions (timing, idle, RPM, PCV restriction, air cleaner restriction and idle mixture ratio). With the introduction of the 1971 models, the NO_x control device was added as a further important device to maintain. Experiments were designed to accommodate a fractional factorial analysis of variance of the five parameters for the pre-control vehicles and the six parameters for the 1971 cars. A 1/2 replicate of the total possible number of combinations of test variables was used in order to hold the number of tests within the program budget while providing statistically meaningful data.

The test sequence for each vehicle began with a complete checkout of the engine and transmission for nominal operating conditions against manufacturer's specifications (not minimum emissions) including replacement as necessary of ignition, induction and emission control components. Emission measurements were made using 1972 Federal Test Procedures, closed 7-mode procedure, the Federal Short Cycle and the Clayton Keymore Cycle under hot engine conditions. Choke effects were measured using the 1972 Federal Test Procedure under cold start conditions. Following baseline emission measurements, the programmed adjustment deviations and/or malfunctions were introduced and the exhaust tests were repeated. The data from the 24 tests of the pre-control vehicles and the 48 tests of the '71 models were used to establish the required influence coefficients.

Detroit Area Engine Adjustment Survey

Two groups of 130 vehicles each, representing pre-controlled cars and later model vehicles with HC/CO controls, were tested in Detroit with the same procedures used initially to establish the maintenance state of vehicles in Los Angeles. (1) The vehicle mix was typical of the Detroit area. The tests were designed to characterize the nature of engine maladjustments in the vehicle population as well as the extent to which these adjustments deviated from manufacturer's specifications. These measurements

(1) A minor exception was the addition of a carburetor float level check to the inspection.

were compared with those made in Los Angeles to determine if vehicle maintenance was significantly different in a location having a colder climate.

Garage Maintenance Evaluation

Ten vehicles were deliberately malfunctioned or maladjusted and sent to service agencies for diagnosis and repair. The malfunctions studied were those identified in earlier experiments as having large effects upon exhaust emissions. Half of the vehicles were sent to the service agencies with instructions to check adjustments, while the others were cited as having failed emission tests. In the later case, the probable cause was identified. No major repairs were allowed. Equal numbers of cars were sent for maintenance to new car dealers, independent garages and service stations. Ninety tests were run in Riverside, California, and 150 were conducted in San Bernardino. Each test vehicle was given a major tune-up before the experiment began. Ignition, induction and emission control components were repaired and adjusted to manufacturer's specifications. Each vehicle then was given emission tests at idle and under two engine load conditions (Clayton Keymodes). When it was clear that the engine met the manufacturer's specifications, the selected malfunctions and maladjustments were deliberately introduced. The Clayton Keymode tests were re-run to establish the experimental emissions baseline. The car was then delivered to the service agency. After maintenance, the vehicle was re-inspected and once again subjected to emission tests using the Clayton Keymodes. In this way, data were obtained on changes in adjustments and in exhaust emissions resulting from the maintenance which was performed. All test data were screened for statistical significance before establishing repair effectiveness coefficients for the Economic Effectiveness Model.

2.3 TOWARD INSPECTION/MAINTENANCE POLICY SELECTION

An inspection/maintenance policy has been defined as a statement of:

- type and place of inspection
- inspection interval
- pass/fail criteria

- extent of maintenance
- facilities configuration

The period over which the policy is evaluated has been chosen to be five years. While this is somewhat less than the average service life of privately owned automobiles, it is sufficient to evaluate inspection and maintenance options and is believed to be consistent with the experimental data.

During policy selection the economics of using state lanes for vehicle inspection is compared with using franchised garages. Maintenance options considered within the Economic Effectiveness Model and their effect on emissions are listed in Table 2-1.

The selection of an optimal inspection and maintenance policy using the Economic Effectiveness Model also specifies the following features of the total system:

- number of inspection lanes
- number of inspection stations
- mobile or fixed sites
- vehicle throughput rates
- information processing configuration
- system manpower
- geographical distribution of stations
- inspection certification procedures

TABLE 2-1 MAINTENANCE OPTIONS AVAILABLE WITHIN THE ECONOMIC EFFECTIVENESS MODEL

Engine Parameter/System	Maintenance Treatment	Relative Emissions Changes HC	CO	NO
Idle:				
Fuel/air ratio	set rich F/A to spec	+1	+3	0
RPM	set slow RPM to spec	+1	-1	0
Timing	set advance to spec	+1	-1	+1
Ignition:				
Misfire	repair as required	+3	0	0
NO_x Control	repair as required	+1	-1	+1
Induction:				
Air Pump	repair or replace	+1	+1	-1
PCV	clean or replace	+1	+1	-1
Air Cleaner	clean or replace	0	+1	-1
Vacuum Kick	set rich to spec	0	+1	0
Heat Riser	free	0	+1	0
		+2	+5	-3

\+ Decrease in emission upon indicated maintenance

\- Increase in emission upon indicated maintenance

Numeral indicates relative magnitude of emissions changes.

3.0 RESULTS

Analytical procedures for evaluating the effectiveness of inspection and maintenance as a means for reducing automotive exhaust emissions have been formulated. Sufficient data have been obtained from the experimental programs to draw a number of basic conclusions about mandatory vehicle inspection and maintenance and to test the sensitivity of these conclusions to assumptions and data uncertainties. About half of the tests to establish emission and engine adjustment deterioration rates have been completed. The other test programs previously described have been completed. The critical elements of cost effective inspection and maintenance programs have been studied and will be reexamined when the final results of the deterioration tests are available. Specific results in the three main sectors of the study (analytical methods, experiments, policy formulation) are described below.

3.1 DESCRIPTION OF THE ECONOMIC EFFECTIVENESS MODEL

Using empirically derived coefficients and data tabulations, the model provides the means to predict exhaust emissions from a vehicle population as a function of time and total emission reductions for a wide range of possible inspection and maintenance strategies. The model incorporates a vehicle emissions prediction model as well as a model to estimate the cost of selected inspection and maintenance procedures. The model also includes descriptions of basic system operations. The model performs a statistical analysis of predicted emission reductions and develops a figure of merit based on statistically significant results. Specialized methods for performing certain data transformations, e.g., integration of emission time histories, are also incorporated into the model.

The Economic Effectiveness Model makes use of a number of subordinate programs described below each of which is capable of independent operation.

Vehicle Emission Models

This series of models simulates vehicle inspection based either on engine adjustments or exhaust emission measurements and accounts for

maintenance effectiveness and engine adjustment deterioration rates. They include a description of three vehicle classes reflecting different levels of emission controls as well as five basic vehicle power trains. These models are based on data from the experimental program and provide the following detailed simulations:

> Inspection Models include data describing ten engine adjustments and six mode emissions which can be used in any combination as a basis for inspecting vehicles. This routine estimates the probability of malfunction detection and distinguishes errors of commission from those of omission.
>
> Deterioration of Engine Adjustments Model provides tabular histograms and linear models of changes in engine adjustments with time.
>
> Maintenance Model provides influence coefficients to transform engine adjustments into emission changes.
>
> Effectiveness of Maintenance Model provides data to estimate the probability of correcting known malfunctions and to predict the cost of unnecessary repairs.
>
> Baseline Emission Prediction Model predicts emissions from a vehicle population subjected to typical voluntary maintenance.

Cost Effectiveness Model

The costs of emission reduction in terms of equivalent tons of emissions are calculated using conventional cost accounting procedures. Future costs are discounted to present value. Capital costs are annualized as a sinking fund for training, equipment, land and facilities. Operating costs include labor and parts and an empirically derived cost of unnecessary repairs. Driver inconvenience is given a value of two dollars an hour.

Operations Research Model

Based on classical queing theory combined with test data, this model determines the length of service ques and estimates inconvenience time as functions of total number of inspection stations and lanes per station.

Statistical Model

In addition to testing for statistical significance, this model estimates the confidence limits of emission reductions and emission time

history profiles. It determines uncertainties in predicting mass emissions at selected times and in estimating emission reductions. The probability that the mean value of emission reduction exceeds an assigned value is also calculated.

Utility Models

Several subroutines serve as operational aids in the manipulation of data. These include an integration package to sum mass emissions by weight over a selected time period, a probability function algorithm to account for mode emission interdependencies and a vehicle population model to account for vehicle attrition and new vehicle production.

Decision Criterion

The figure of merit is defined as the cost of the proposed program divided by the species-weighted reduction in emissions. The decision model permits evaluation of the components of the ratio as well as the ratio itself.

3.2 EXPERIMENTAL PROGRAM

The test program has furnished data to characterize engine adjustment and exhaust emission deterioration effects, to correlate changes in engine settings with exhaust emissions, to estimate regional influences, and to evaluate garage maintenance effectiveness.

Engine Adjustment and Exhaust Emission Deterioration Tests

Of the 450 vehicles obtained for the test, 416 were processed through the first test recall (4 months) and 233 through the second recall (8 months). Analysis of data from the first and second recall periods provided the following results.

Effects of Initial Maintenance - Changes in emissions and engine settings resulting from the initial tune-up of the test vehicle population are summarized in Table 3-1. Significant emission changes occurred in the pre 1966 vehicles where the CO and HC reductions were 7 and 10 percent respectively. Emission reductions

TABLE 3-1

AS RECEIVED VEHICLE PARAMETERS & THEIR CHANGE WITH MAINTENANCE

PARAMETERS	PRE-EMISSION CONTROLLED VEHICLES					EMISSION CONTROLLED VEHICLES					NO_x CONTROLLED VEHICLES				
	AS RECEIVED	CHANGE DUE TO TUNE				AS RECEIVED	CHANGE DUE TO TUNE				AS RECEIVED	CHANGE DUE TO TUNE			
	$\bar{X}$	$\overline{\Delta X}$	S	d.f.	t	$\bar{X}$	$\overline{\Delta X}$	S	d.f.	t	$\bar{X}$	$\overline{\Delta X}$	S	d.f.	t
HC 72 COLD, g/mile	12.00	-1.22	5.6	147	-2.64*	7.25	-1.00	5.5	149	-2.23*	4.44	-0.05	1.9	148	-0.32
CO 72 COLD, g/mile	131.5	-9.0	48	147	-2.31*	86.9	-6.30	37	149	-2.10*	63.4	-5.5	29	147	-2.29*
NOX 72 COLD, g/mile	3.97	0.27	1.6	147	2.01*	6.33	0.17	2.2	149	0.94	5.95	-0.14	1.6	148	-1.07
HC D1 (49/45), ppm	383	-121	447	147	-3.35*	222	-38.8	332	147	-1.42	135	-7.90	48	148	-2.01*
CO D1 (49/45), % v	3.45	-0.260	2.0	147	-1.60	1.22	0.048	0.73	149	0.81	0.87	-0.063	0.95	148	-0.81
NOX D1 (49/45), ppm	1666	103.0	633	147	1.98*	2613	20.5	714	149	0.35	2537	13.2	570	147	0.28
HC D3 (IDLE), ppm	865	-117	857	146	-1.66	376	-66.4	516	148	-1.57	240	-40.4	194	148	-2.55*
CO D3 (IDLE), % v	6.08	-0.26	3.2	147	-1.02	4.09	-0.82	2.7	149	-3.68*	3.34	-0.52	2.5	148	-2.51*
NOX D3 (IDLE), ppm	126.8	-23.1	135	147	-2.09*	124.2	18.4	141	149	1.60	168	3.46	84	147	0.50
TIMING, degrees (DV)	0.35	-0.35	5.7	147	-0.75	0.50	-0.46	4.7	146	-1.19	0.17	-0.13	3.3	147	-0.49
IRPM, rpm (DV)	77.9	-61	140	147	-5.31*	-18.2	19	108	148	2.11*	-5.68	13.8	94	149	1.81
AIR CLN ANGLE, degrees	60.0	-28.4	51	133	-6.43*	45.6	-22.4	48	134	-5.37*	28.8	-13.2	34	128	-4.39*
PCV FLO D1, cfm	2.87	0.16	1.5	126	1.21	2.62	-0.0011	0.99	138	-0.01	2.58	0.046	0.84	134	0.64
CHOKE KICK, in.	9.24×10^{-3}	-9.22×10^{-3}	0.050	79	-1.64	-4.42×10^{-3}	2.98×10^{-3}	0.047	122	0.70	-9.56×10^{-3}	9.81×10^{-3}	0.039	127	-2.82*
MILEAGE, miles	83358	-	-	-	-	43786	-	-	-	-	8059	-	-	-	-

*Estimates of means significant (confidence equal to or greater than 90%).

for the 1966-1970 vehicles were also 7 and 14 percent for CO and HC with a minor increase in NO_x. A small reduction in CO was obtained in the relatively new NO_x controlled 1971 models.

These data were used for example to show that screening of vehicles based on idle mode emissions is effective in finding vehicles having component failures and maladjustments. The malfunction or maladjustment rates in a population screened using idle mode emissions were 2 to 3 times higher than those in the population at large.

Deterioration of Engine Adjustments and Exhaust Emissions - This test program is not yet completed. However, based on data presently available, the most significant results of the deterioration experiments are:

- deterioration effects which were statistically significant at confidence levels above 90% were found for half of the adjustments investigated
- the emission data had greatest consistency when the 1972 Federal Test Procedure was used
- the greatest degradation (increase) in HC emissions was measured for pre 1966 vehicles, while no average change in HC emissions was measured for NO_x controlled vehicles (post 1970)
- CO emission increases were found for all vehicle classes but the emission deterioration rate was much less in newer cars
- no significant change was found in the mean value of basic timing, only in the dispersion of this adjustment
- an increase in mean idle rpm was found for the pre 1966 vehicles only but the dispersion of this adjustment increased in all vehicle groups
- idle fuel to air ratio was found to become more rich with time with this effect being smaller in newer vehicles
- some degradation was found of the air cleaner, choke kick adjustment and ignition

- substantial failure rates were found for vacuum diaphragms, air pumps and NO_x control devices.

Experiments to Establish the Relationship Between Engine Adjustments and Emissions (Orthogonal Experiments)

These statistically designed experiments relate engine adjustments to exhaust emissions measured on both a mass and concentration basis. The population weighted emission responses for pre-control (pre 1966) and NO_x controlled (1971) vehicles are summarized below:

	Pre-Control Vehicles	NO_x Control	Response Units	HC	CO	NO_x
Timing Advance	X		gm/mi deg	.066	-.85	.14
Timing Advance		X	gm/mi deg	.078	-.90	.15
Idle Speed	X		gm/mi rpm	-.0029	.029	.00073
Idle Speed		X	gm/mi rpm	.0005	.028	.00066
Idle Fuel to Air Ratio	X		gm/mi%CO var	.44	4.03	.21
Idle Fuel to Air Ratio		X	gm/mi%CO var	.067	6.53	-.034
Air Cleaner Restriction	X		gm/mi deg*	.0057	.112	-.0030
Air Cleaner Restriction		X	gm/mi deg*	.00089	.069	-.0024
PCV Restriction	X		gm/mi CFM	.060	-1.91	.029
PCV Restriction		X	gm/mi CFM	-.122	-6.01	.105

* Degrees of blocking using an AC tester

Emission response to engine adjustments also was investigated for two constant speed operating modes. Table 3-2 presents a comparison of weighted population emission responses for the engine adjustments and engine components investigated. It is significant to note that with few exceptions, engine malfunctions and maladjustments influence emission modes similarly for all three classes of vehicles studied. Thus, it is reasonable to anticipate that the same emission inspection procedures will be applicable to all groups. Of course, because of the substantially lower exhaust emissions of '71 vehicles, the pass/fail criteria must be set lower for these vehicles.

TABLE 3-2

EMISSION RESPONSE TO ENGINE PARAMETERS IN TWO CONSTANT SPEED OPERATING MODES

Engine Parameter	Emission	49/45 MPH Cruise Mode		Idle Mode	
		Pre-emission Controlled Vehicles	NOX Controlled Vehicles	Pre-emission Controlled Vehicles	NOX Controlled Vehicles
Timing	HC, ppm	4.20	4.05	17.8	11.5
	CO, %	- .0086	- .0116	.0032	.00031
	NO_x, ppm	73.4	91.6	.735	.429
Idle Speed	HC, ppm	- .022	- .023	-1.66	-.342
	CO, %	0	0	0	-.0042
	NO_x, ppm	.201	- .043	.058	.386
Idle F/A	HC, ppm	- 2.25	.603	34.8	13.5
	CO, %	.0132	- .011	.900	1.03
	NO_x, ppm	0	- 1.77	- 9.44	-38.3
PCV	HC, ppm	- 5.19	- 6.85	0	- 2.96
	CO, %	- .053	- .142	- .0136	- .0125
	NO_x, ppm	-72.3	53.8	- 1.04	- 3.94
Air Cleaner	HC, ppm	.080	.086	.047	- .094
	CO, %	.0016	.0029	0	.00008
	NO_x, ppm	- .925	- .695	- .0079	- .044
NO_x	HC, ppm	--	11.2	--	105
	CO, %	--	- .015	--	.025
	NO_x, ppm	--	313	--	40

emission mode(s) with greatest relative sensitivity

best mode

Engine malfunctions affecting cold start emissions were also investigated. Three vacuum kick settings (normal ± 50%) and two heat riser settings (normal, stuck open) were tested. The results were inconclusive, because of large variability in the data. Although emission changes were large, only about 10% of the tests were statistically significant at the 90% confidence level.

Detroit Area Engine Adjustment Survey

Vehicle maintenance states were contrasted between Detroit and San Bernardino for similar vehicle fleets sorted by emission control type. The results of this analysis, estimates of the mean ($\bar{X}$), standard deviation (S) and degrees of freedom (d.f.), are presented in Table 3-3. A statistical comparison of the exhaust emissions and engine adjustments for the two regions studied indicated a few population differences which were statistically significant at the 90% confidence level. The carbon monoxide emission levels measured in the high cruise and idle modes are higher in San Bernardino vehicle fleets than in Detroit. The choke kick adjustment was set richer in Detroit than San Bernardino. The lower exhaust emissions measured in Detroit may be the result of a number of factors including more advanced emission control equipment, lower average accumulated vehicle mileage and basic maintenance differences. The lower frequency and level of misfire in Detroit cars substantially explains the lower HC emissions; however, the induction related malfunctions affecting CO are not substantially different for the two regions.

To determine whether or not mileage and model year effects were causing the differences observed in the exhaust emissions and engine adjustment states, data from the vehicle fleet in Detroit was partitioned by model year rather than emission control type. These comparisons show that only CO keymode emissions for the 1960-65 vehicles were significantly different. The Detroit vehicles tended again to have lower CO emissions, but the mileage accumulation of the Detroit fleet vehicles was still markedly less than that of the San Bernardino vehicles.

TABLE 3-3

COMPARISON OF SAN BERNARDINO & DETROIT AS RECEIVED EMISSION & ENGINE PARAMETER DISTRIBUTIONS

PARAMETERS	PRE-EMISSION CONTROLLED VEHICLES							EMISSION CONTROLLED VEHICLES							NOX CONTROLLED VEHICLES		
	SAN BERNARDINO (1960-1965)			DETROIT (1960-1967)				SAN BERNARDINO (1966-1970)			DETROIT (1968-1971)				SAN BERNARDINO (1971)		
	$\bar{X}$	S	d.f.	$\bar{X}$	S	d.f.	t	$\bar{X}$	S	d.f.	$\bar{X}$	S	d.f.	t	$\bar{X}$	S	d.f.
HC 72 COLD, g/mile	12.00	7.0	147	-	-	-	-	7.25	5.7	149	-	-	-	-	4.44	1.8	149
CO 72 COLD, g/mile	131.5	63	147	-	-	-	-	86.9	46	149	-	-	-	-	63.4	37	149
NOX 72 COLD, g/mile	3.97	2.0	147	-	-	-	-	6.33	2.6	149	-	-	-	-	5.95	2.0	149
HC D1 (49/45), ppm	383	450	147	332	374	129	1.02	222	306	148	198	107	128	0.84	135	56	149
CO D1 (49/45), % v	3.43	2.6	147	1.64	1.5	129	7.13*	1.22	1.3	149	0.69	0.81	128	4.03*	0.87	1.16	149
NOX D1 (49/45), ppm	1666	864	147	-	-	-	-	2613	976	149	-	-	-	-	2537	740	149
HC D3 (Idle), ppm	865	989	146	603	582	128	2.64*	376	546	148	300	230	128	1.55	240	199	149
CO D3 (Idle), % v	6.08	3.0	147	4.50	3.1	129	4.41*	4.09	2.6	149	3.15	2.5	128	3.08*	3.34	2.7	149
NOX D3 (Idle), ppm	126.8	122	147	-	-	-	-	124.2	82	149	-	-	-	-	168	96	149
TIMING, degrees (DV)	0.35	5.7	148	0.62	6.0	123	-0.38	0.50	4.6	149	1.07	3.7	124	-1.11	0.17	3.4	147
IRPM, rpm (DV)	77.9	137	148	108.5	146	129	-1.81	-18.2	108	149	2.5	90	126	-1.72	-5.68	138	149
AIR CLN ANGLE, degrees	60.0	53	137	61.7	45	113	-0.27	45.6	53	137	47	44	117	-0.23	28.8	43	130
PCV FLO D1, cfm	2.87	1.3	126	2.86	1.3	87	0.05	2.62	0.97	138	2.85	1.2	118	-1.71	2.58	0.90	135
CHOKE KICK, in (DV)	9.24×10^{-3}	4.88×10^{-2}	79	-.0511	0.0654	97	6.85*	-4.42×10^{-3}	4.6×10^{-2}	122	-.0372	0.0643	98	4.43*	-9.56×10^{-3}	4.06×10^{-2}	126
HEAT RISER, % failed	53.1	-	80	68.0	-	77	-	44.0	-	74	42.5	-	65	-	3.4	-	29
VACUUM DIAPH, % failed	25.0	-	27	32.6	-	42	-	21.7	-	91	21.3	-	79	-	0.0	-	123
MISFIRE D1, %	12.3	11.3	6	14.5	1.8	4	-0.51	2.6	0.4	2	4.7	0.4	1	-5.75	-	-	-
MISFIRE D2, %	14.4	9.6	6	15.1	1.7	4	-0.18	4.6	3.6	2	4.8	2.4	1	-0.07	-	-	-
MISFIRE D3, %	17.5	12.0	6	13.9	3.8	4	0.74	11.5	9.7	2	4.2	0.9	1	1.30	-	-	-
AIR PUMP, % failed	-	-	-	-	-	-	-	8.1	-	37	-	-	-	-	-	-	-
NOX CONTROL, % failed	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.9	-	81
MILEAGE, miles	83358	26047	148	58280	19377	129	-	43786	20567	148	27863	17340	128	-	8059	6451	149

*Estimates of means significantly different (confidence equal to or greater than 90%).

In comparing the emission controlled vehicle fleets of the two cities for which the average accumulated mileage was similar, no statistically significant differences in the emission levels were found. Significant differences in Idle RPM, PCV Valve Flowrate (49/45 mph Cruise) and the choke kick adjustments were observed. These deviations are in the direction which would explain the somewhat higher CO emissions in the San Bernardino fleet.

With 1971 vehicles, the HC measurements made during the 49/45 mph cruise and the CO measurements taken at idle were found to be significantly different in the two regions. The choke kick adjustments for the fleets also were found to be significantly different.

In general, the data indicate reasonable agreement in the distribution of engine adjustments for the vehicles of the two cities. Some of the adjustments such as Idle RPM which appeared to be set higher in Detroit seem reasonable because of the colder climate. It was surprising, however, that there were equally large numbers of heat riser valve failures in the Detroit vehicle fleets as there were in the San Bernardino fleets.

Diagnostic Content of Exhaust Emissions Measured in Selected Modes

Previous tests had revealed the difficulty of detecting specific engine malfunctions from emission measurements. It was shown that emissions measured in intermediate cruise modes add little information useful in identifying malfunctions to that obtained from measurements made in idle and high cruise modes. Further it was found to be ineffective to combine more than two emission mode measurements to identify malfunctions. Nonetheless, experimental data from the Los Angeles and Detroit fleet tests were reexamined to estimate the probability of malfunction diagnosis using exhaust emission measurements. Seventy-two case studies were performed using various "cutpoints" as trial limits for engine adjustments which cause high emissions. Detection (failure isolation) probabilities were generally low. Only the following exceeded 10%:

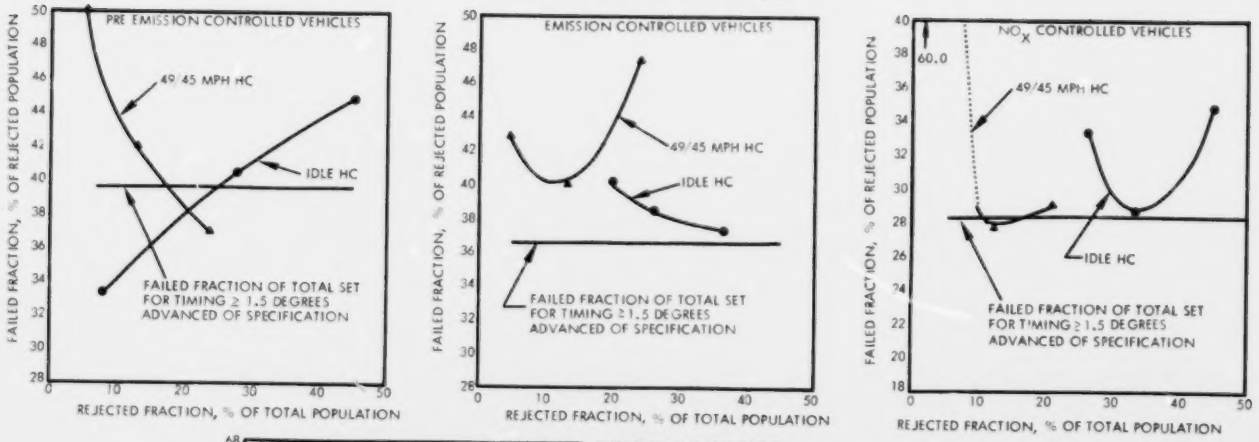
- o idle mode HC as an indication of timing error
- o cruise mode HC or CO an an indication of air cleaner restriction
- o idle mode HC as an indication of idle rpm error

The use of emission measurements to screen a vehicle population for those having probability of maladjustments and malfunctions is a more promising approach than the use of emission measurements for failure isolation. Figures 3-1 through 3-4 show that deviate engine conditions are revealed fairly consistently (although ambiguously) by mode emission tests. In these figures the percent of vehicles having a maladjustment equal to or greater than the level indicated are plotted on the ordinate versus the percent of the total population rejected by adjusting the emission mode inspection criterion. The percent of vehicles in the total population having the malajustment also is shown. If the failed fraction in the rejected population is greater than that of the population as a whole, then the emission inspection mode is beneficial as a vehicle screening tool.

FIGURE 3-1

ANALYSIS OF EMISSION SIGNATURE CUT POINT - TIMING

SAN BERNARDINO VEHICLES


PRE EMISSION CONTROLLED VEHICLES
49/45 MPH HC
IDLE HC
FAILED FRACTION OF TOTAL SET FOR TIMING ≥ 1.5 DEGREES ADVANCED OF SPECIFICATION
FAILED FRACTION, % OF REJECTED POPULATION
REJECTED FRACTION, % OF TOTAL POPULATION
EMISSION CONTROLLED VEHICLES
49/45 MPH HC
IDLE HC
FAILED FRACTION OF TOTAL SET FOR TIMING ≥1.5 DEGREES ADVANCED OF SPECIFICATION
FAILED FRACTION, % OF REJECTED POPULATION
REJECTED FRACTION, % OF TOTAL POPULATION
NO_X CONTROLLED VEHICLES
60.0
49/45 MPH HC
IDLE HC
FAILED FRACTION OF TOTAL SET FOR TIMING ≥ 1.5 DEGREES ADVANCED OF SPECIFICATION
FAILED FRACTION, % OF REJECTED POPULATION
REJECTED FRACTION, % OF TOTAL POPULATION

DETROIT VEHICLES

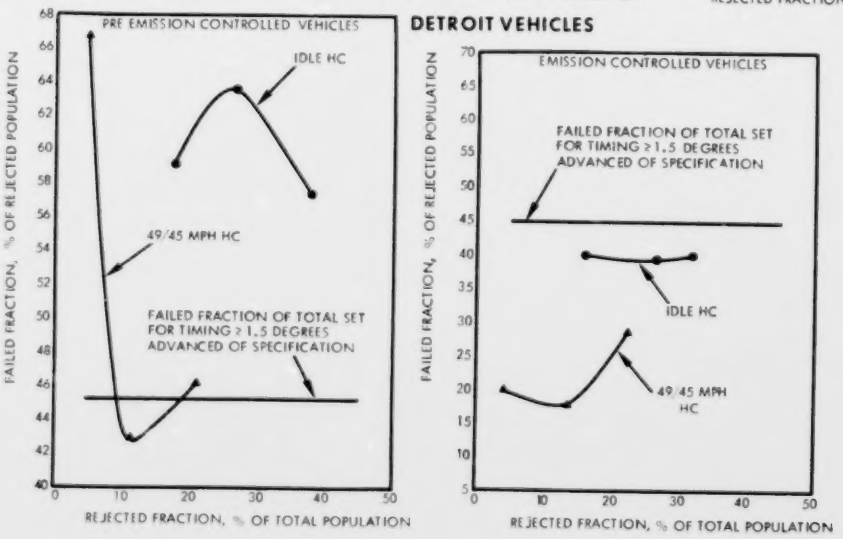

PRE EMISSION CONTROLLED VEHICLES
IDLE HC
49/45 MPH HC
FAILED FRACTION OF TOTAL SET FOR TIMING ≥ 1.5 DEGREES ADVANCED OF SPECIFICATION
FAILED FRACTION, % OF REJECTED POPULATION
REJECTED FRACTION, % OF TOTAL POPULATION
EMISSION CONTROLLED VEHICLES
FAILED FRACTION OF TOTAL SET FOR TIMING ≥ 1.5 DEGREES ADVANCED OF SPECIFICATION
IDLE HC
49/45 MPH HC
FAILED FRACTION, % OF REJECTED POPULATION
REJECTED FRACTION, % OF TOTAL POPULATION

FIGURE 3-2

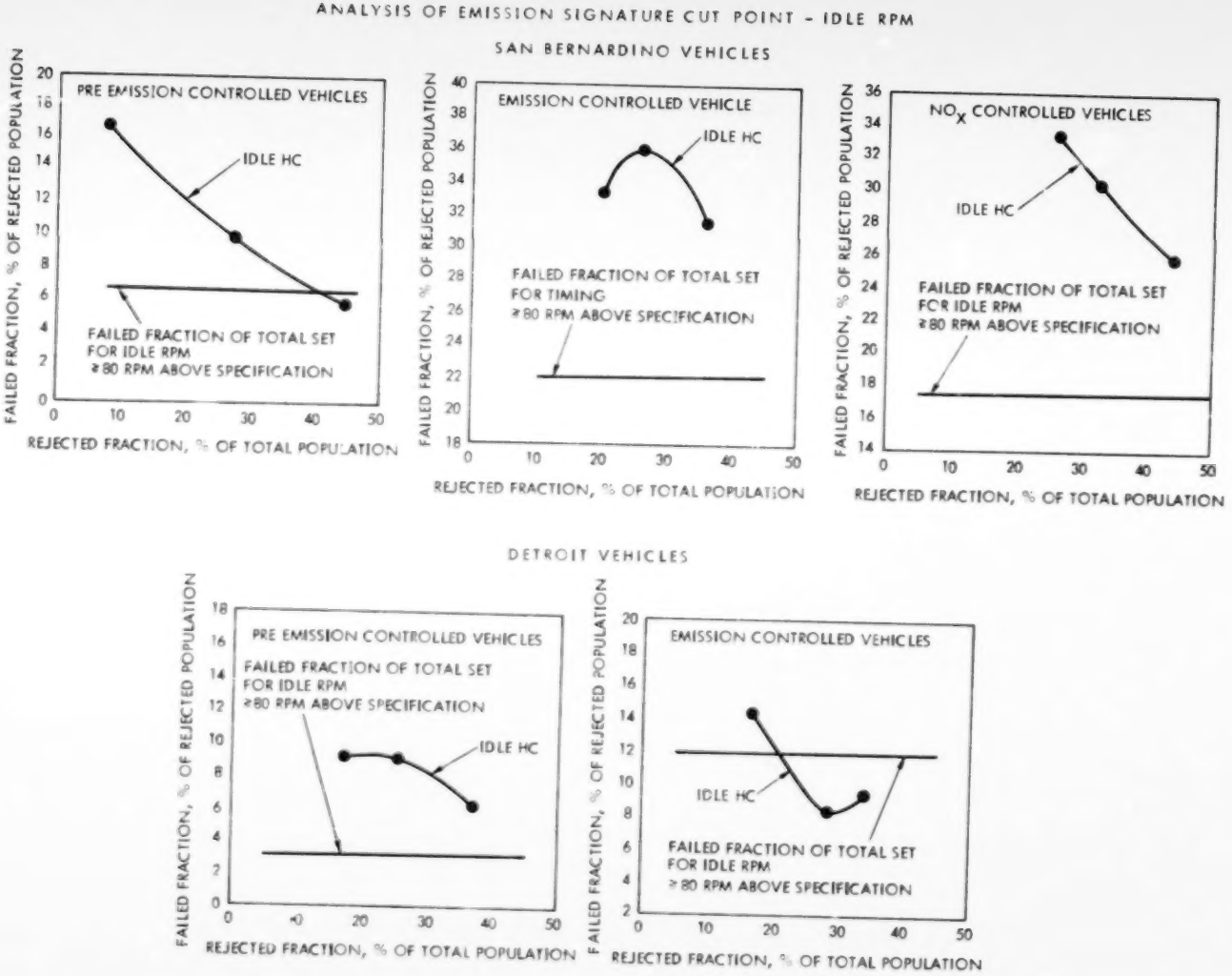
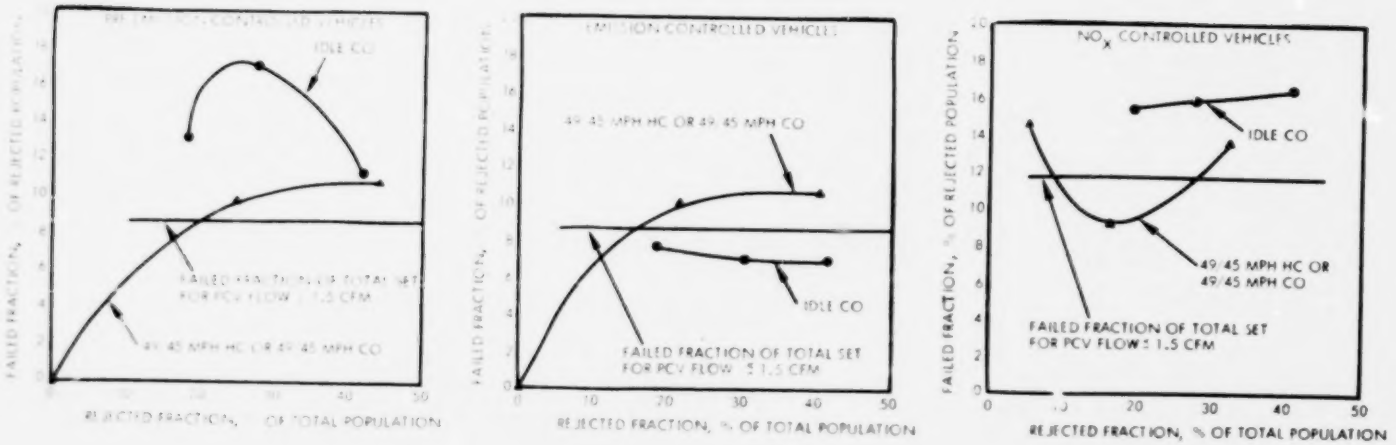

ANALYSIS OF EMISSION SIGNATURE CUT POINT - IDLE RPM
SAN BERNARDINO VEHICLES
PRE EMISSION CONTROLLED VEHICLES
IDLE HC
FAILED FRACTION OF TOTAL SET
FOR IDLE RPM
≥80 RPM ABOVE SPECIFICATION
FAILED FRACTION, % OF REJECTED POPULATION
REJECTED FRACTION, % OF TOTAL POPULATION
EMISSION CONTROLLED VEHICLE
IDLE HC
FAILED FRACTION OF TOTAL SET
FOR TIMING
≥80 RPM ABOVE SPECIFICATION
FAILED FRACTION, % OF REJECTED POPULATION
REJECTED FRACTION, % OF TOTAL POPULATION
NOx CONTROLLED VEHICLES
IDLE HC
FAILED FRACTION OF TOTAL SET
FOR IDLE RPM
≥80 RPM ABOVE SPECIFICATION
FAILED FRACTION, % OF REJECTED POPULATION
REJECTED FRACTION, % OF TOTAL POPULATION
DETROIT VEHICLES
PRE EMISSION CONTROLLED VEHICLES
FAILED FRACTION OF TOTAL SET
FOR IDLE RPM
≥80 RPM ABOVE SPECIFICATION
IDLE HC
FAILED FRACTION, % OF REJECTED POPULATION
REJECTED FRACTION, % OF TOTAL POPULATION
EMISSION CONTROLLED VEHICLES
IDLE HC
FAILED FRACTION OF TOTAL SET
FOR IDLE RPM
≥80 RPM ABOVE SPECIFICATION
FAILED FRACTION, % OF REJECTED POPULATION
REJECTED FRACTION, % OF TOTAL POPULATION

FIGURE 3-3

ANALYSIS OF EMISSION SIGNATURE CUT POINT - PCV FLOW

SAN BERNARDINO VEHICLES


IDLE CO
49/45 MPH HC OR 49/45 MPH CO
FAILED FRACTION OF TOTAL SET FOR PCV FLOW ≤ 1.5 CFM
EMISSION CONTROLLED VEHICLES
49/45 MPH HC OR 49/45 MPH CO
IDLE CO
FAILED FRACTION OF TOTAL SET FOR PCV FLOW ≤ 1.5 CFM
NO_x CONTROLLED VEHICLES
IDLE CO
49/45 MPH HC OR 49/45 MPH CO
FAILED FRACTION OF TOTAL SET FOR PCV FLOW ≤ 1.5 CFM
FAILED FRACTION, % OF REJECTED POPULATION
REJECTED FRACTION, % OF TOTAL POPULATION

DETROIT VEHICLES

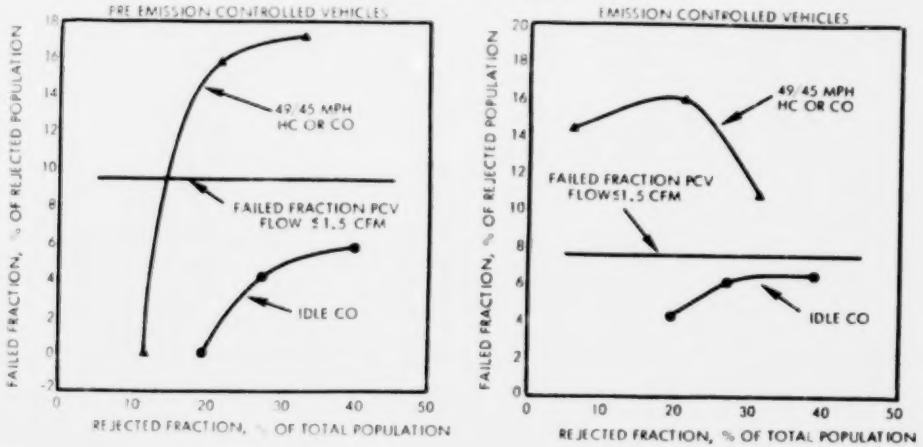
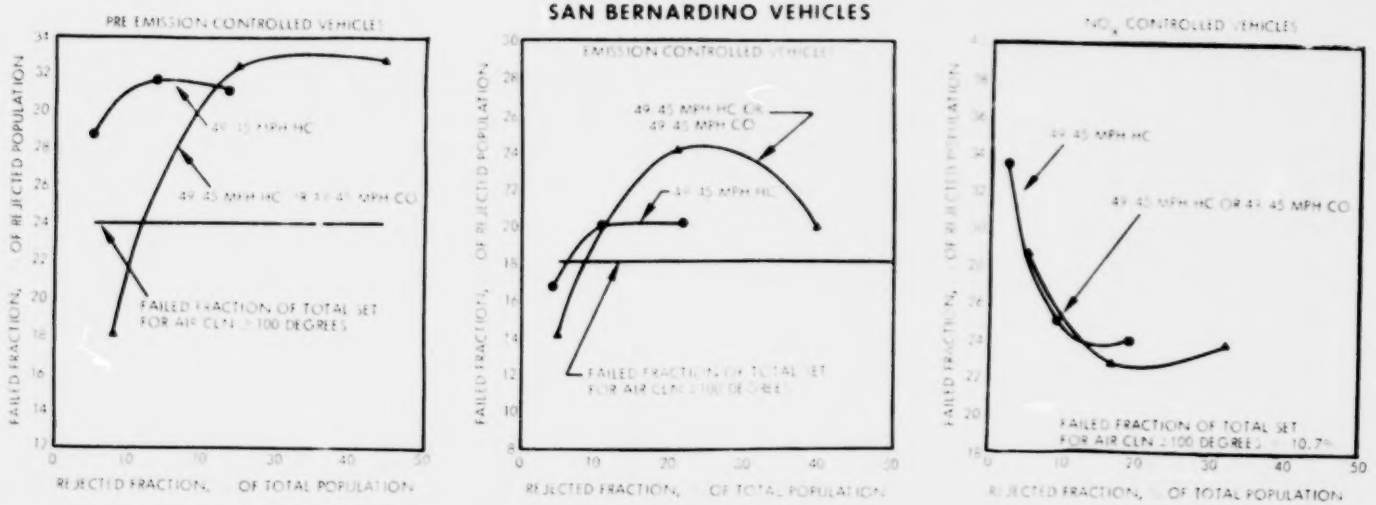

PRE EMISSION CONTROLLED VEHICLES
49/45 MPH HC OR CO
FAILED FRACTION PCV FLOW ≤1.5 CFM
IDLE CO
EMISSION CONTROLLED VEHICLES
49/45 MPH HC OR CO
FAILED FRACTION PCV FLOW≤1.5 CFM
IDLE CO
FAILED FRACTION, % OF REJECTED POPULATION
REJECTED FRACTION, % OF TOTAL POPULATION

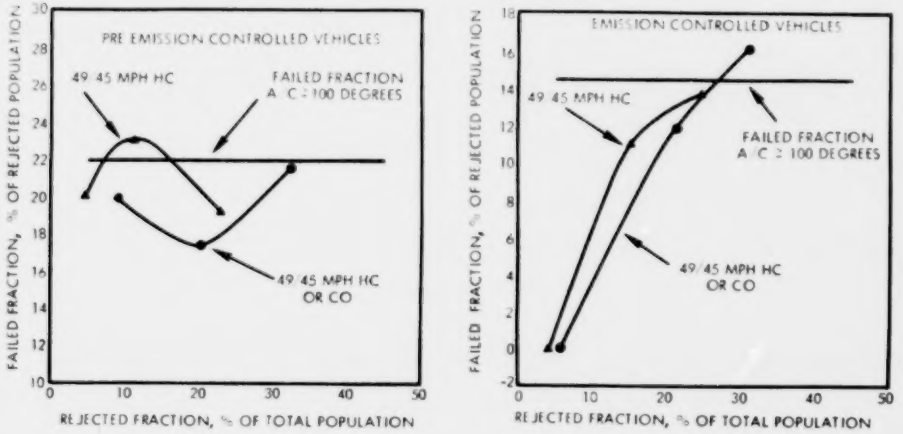
FIGURE 3-4

ANALYSIS OF EMISSION SIGNATURE CUT POINT - AIR CLEANER

SAN BERNARDINO VEHICLES


PRE EMISSION CONTROLLED VEHICLES
49-45 MPH HC
49-45 MPH HC OR 49-45 MPH CO
FAILED FRACTION OF TOTAL SET FOR AIR CLN ≥ 100 DEGREES
FAILED FRACTION, % OF REJECTED POPULATION
REJECTED FRACTION, % OF TOTAL POPULATION
EMISSION CONTROLLED VEHICLES
49-45 MPH HC OR 49-45 MPH CO
49-45 MPH HC
FAILED FRACTION OF TOTAL SET FOR AIR CLN ≥ 100 DEGREES
FAILED FRACTION, % OF REJECTED POPULATION
REJECTED FRACTION, % OF TOTAL POPULATION
NOx CONTROLLED VEHICLES
49-45 MPH HC
49-45 MPH HC OR 49-45 MPH CO
FAILED FRACTION OF TOTAL SET FOR AIR CLN ≥ 100 DEGREES = 10.7%
FAILED FRACTION, % OF REJECTED POPULATION
REJECTED FRACTION, % OF TOTAL POPULATION

DETROIT VEHICLES


PRE EMISSION CONTROLLED VEHICLES
49-45 MPH HC
FAILED FRACTION A/C ≥ 100 DEGREES
49-45 MPH HC OR CO
FAILED FRACTION, % OF REJECTED POPULATION
REJECTED FRACTION, % OF TOTAL POPULATION
EMISSION CONTROLLED VEHICLES
49-45 MPH HC
FAILED FRACTION A/C ≥ 100 DEGREES
49-45 MPH HC OR CO
FAILED FRACTION, % OF REJECTED POPULATION
REJECTED FRACTION, % OF TOTAL POPULATION

Maintenance Effectiveness Evaluation

The performance effectiveness of all the types of service organizations tested was marginal to poor for vehicles in both the engine inspection and emission inspection fleets. A summary of the fraction of malfunctions and maladjustments corrected by each class of service organization is presented in Table 3-4. The data were obtained by pooling test results obtained in the San Bernardino and Riverside areas. This table shows that up to 52% of the emissions related malfunctions and maladjustments remained uncorrected following maintenance. Successful maintenance performance ranged from 48-68%. These data further suggest that some types of service organizations perform better than others. Table 3-5 shows the range of detection and the range of successful repair of engine malfunctions. It indicates that the detection of a malfunction does not guarantee a successful repair. For example, the detection rate for an idle fuel-to-air ratio maladjustment ranged from 55% to 100% while the ability of the service organizations to adjust this parameter to within $\pm$1% of manufacturer's specifications ranged from complete failure to a maximum of 52%. Similar discrepancies between maladjustment detection and repair can also be seen for idle rpm, timing and choke kick. Detection and repair percentages were identical for the other malfunctions studied because the repair generally entailed the replacement of a faulty part rather than an adjustment to specification.

TABLE 3-4

MALFUNCTIONS DETECTED AND CORRECTED

	Independent Garages		Dealerships		Service Stations	
	Emission Vehicles	Parameter Vehicles	Emission Vehicles	Parameter Vehicles	Emission Vehicles	Parameter Vehicles
Total Malfunctions Submitted	133	242	134	239	140	243
Malfunctions Found and Corrected	73	122	92	120	85	119
Malfunctions Not Corrected	60	120	42	119	55	124
Percent Malfunctions Found and Corrected	54%	50%	68%	50%	60%	48%

TABLE 3-5

RANGE OF DETECTION OR REPAIR OR MALFUNCTIONED PARAMETERS FOR ALL VEHICLES UNDER ALL EXPERIMENTAL CONDITIONS

Parameter	Detection, %	Repair, %	Repair Type
Idle CO	55 to 100	0 to 52	Adjustment
Idle RPM	67 to 100	45 to 73	"
Basic Timing	50 to 89	33 to 78	"
NO_x Control Device	12 to 41	12 to 41	Parts Replacement
Spark Plug Wire Misfire	25 to 100	25 to 100	Parts Repair or Replacement
Spark Plug Misfire	50 to 96	50 to 96	Parts Replacement
Air Cleaner	67 to 86	67 to 86	"
PCV Valve	50 to 90	50 to 90	"
Heat Riser Valve	15 to 67	15 to 67	Parts Repair
Choke Kick	27 to 37	15 to 18	Adjustment

3.3 EVALUATION AND SELECTION OF INSPECTION AND MAINTENANCE PROCEDURES

The computer model was used with the developed experimental data base to evaluate the economic effectiveness of a number of different inspection and maintenance procedures. Two basic types of inspection procedures were evaluated:

- The direct inspection of specific engine components for malfunction or maladjustment.
- The measurement of exhaust emissions in selected vehicle operating modes to diagnose possible engine component failures.

Vehicle inspections of both types are followed, as necessary, by a specified maintenance treatment which is directly related to the class of malfunctions and maladjustments which can be adequately diagnosed in the inspection process.

The results presented in this section are subject to the following study ground rules and assumptions:

- Estimated emission reductions are based on measurements using the 1972 Federal Emission Test Procedure.
- Mass emission levels and reduction percentages are reported as averages for the entire vehicle population.
- A simple average is used to estimate the emission reductions over the period of the program.
- Fail/pass criteria are based on specific engine adjustments and/or mode emissions and not on composite mass emission levels.
- Pass/fail criteria are selected for the first inspection interval and are not changed thereafter.
- Engine adjustment and emissions deterioration rates as well as the influence of engine adjustments upon emissions do not change from one inspection interval to another.
- After the first inspection and repair procedure, engine malfunctions are statistically independent and randomly distributed throughout the population.
- The vehicle population mix changes with time to reflect vehicle attrition and new vehicle purchases.
- Labor and parts costs are based on Chilton's Guide.
- User inconvenience for inspection is valued at two dollars an hour (social cost) but economic benefits resulting from properly tuned vehicles are not credited.

Table 3-6 lists the basic inspection and maintenance procedures studied on this program and identifies the inspection process and the specific engine malfunctions and maladjustments maintained. Performance and cost of these procedures is described in the following paragraphs.

TABLE 3-6

INSPECTION AND MAINTENANCE PROCEDURES STUDIED

Engine Parameter Inspection	Inspection/Maintenance Procedure
Idle (Franchised Garage)	Inspect and Adjust ICO, RPM, Timing
Extensive A (Franchised Garage with Dynamometer)	Inspect and Adjust ICO, RPM, Timing Repair Misfire and NO_X Control
Extensive B (Franchised Garage with Dynamometer)	Inspect and Adjust ICO, RPM, Timing Repair Misfire, Air Pump, PCV Valve, Air Cleaner, NO_X Control, Choke System
Emission Inspection	
Idle (State Lane)	Measure ICO, IHC; Adjust ICO, RPM, Timing
Extensive A (State Lane Emission Under Load	Measure ICO, IHC, LHC; Adjust ICO, RPM, Timing; Repair Misfire and NO_X Control
Extensive B (State Lane Emission Under Load)	Measure ICO, IHC, LHC, LCO; Adjust ICO RPM, Timing; Repair Misfire, PCV Valve, Air Cleaner

---

ICO, Idle CO Emission Measurement
IHC, Idle HC Emission Measurement
LHC, Loaded Mode HC Emission Measurement, 45/49 MPH Key Mode
LCO, Loaded Mode CO Emission Measurement, 45/49 MPH Key Mode

Table 3-7 presents a comparison of optimal system performance derived from this study with that presented in the interim report. The program figures of merit for all strategies studied in the current analysis have become dramatically poorer relative to the interim results. In some instances (engine parameter inspection followed by idle adjustments and repair of the ignition system) the cost per weighted unit of emission reduction has risen over sevenfold. This degradation in system performance can be attributed directly to higher program costs, ineffective garage maintenance and lower emission deterioration rates.

A complete set of results from the current analysis is given in Table 3-8. The engine parameter inspection strategy is seen to be less cost effective across all maintenance treatments than is the emission inspection procedure. This occurs even though the engine parameter inspection strategy produces larger emission reductions.

The "best" procedure (i.e., the one having the lowest average figure of merit of 730) is an idle CO emission inspection followed by the adjustment of the carburetor idle fuel-to-air ratio. However, this "best" procedure does not greatly reduce exhaust emissions and, therefore, may be of little practical interest.

The next two most cost effective procedures, an inspection of the idle adjustments followed by their maintenance and an emission inspection followed by both idle adjustments and ignition maintenance, have figures of merit of 950 and 1305, respectively. The emission inspection procedure is over three times more effective in reducing HC, has little additional influence on CO, and costs 2.5 times as much as the idle parameter inspection and maintenance procedure. The emission inspection procedure also has the lowest figure of merit (915) of all procedures when calculated using the emission reduction at the end of the fifth year estimated at the 90% confidence level. Because of this favorable figure of merit and the large HC emissions reductions achieved (8% average and 16% in the fifth year), this procedure might be attractive for the L.A. basin.

TABLE 3-7

COMPARISON OF INTERIM AND YEAR-END OPTIMAL RESULTS
FOR BASIC INSPECTION/MAINTENANCE PROCEDURES

INSPECTION/MAINTENANCE PROCEDURES	FIGURE OF MERIT $/TON+++		COST PER VEHICLE		EMISSION REDUCTIONS, PERCENT HC		CO		NOx	
	I	F	I	F	I	F	I	F	I	F
ENGINE PARAMETER INSPECTION										
1. IDLE (FRANCHISED)	200	950	3.00	4.00	4.0	2.4	6.0	2.6	6.0	-0.2
2. EXTENSIVE A+ (FRANCHISED)	230	1780	7.00	11.30	21.0	10.8	6.0	2.6	6.0	-0.2
3. EXTENSIVE B++ (FRANCHISED)	350	1975	13.50	24.80	23.0	11.6	12.0	5.1	3.0	-1.1
EXHAUST EMISSION INSPECTION										
4. IDLE (STATE LANE)	225	730	1.90	3.20	0.0	1.5	6.0	2.9	2.0	-0.0
5. EXTENSIVE A+ (STATE LANE)	190	1305	2.50	10.10	9.0	7.9	6.0	2.9	2.0	-0.0
6. EXTENSIVE B++ (STATE LANE)	320	1475	5.75	12.35	9.0	8.1	8.0	3.4	0.0	-0.3

\+ IDLE PLUS IGNITION TUNEUP, WITH DYNAMOMETER

++ IDLE PLUS IGNITION PLUS INDUCTION TUNEUP WITH DYNAMOMETER

+++ L.A. BASIN WEIGHTING FUNCTION

I: INTERIM REPORT RESULTS

F: YEAR END REPORT RESULTS

TABLE 3-8

COMPARISON OF OPTIMAL RESULTS FOR BASIC INSPECTION/MAINTENANCE PROCEDURES

INSPECTION/MAINTENANCE PROCEDURES	FIGURE OF MERIT $/TON+++			COST PER VEHICLE		EMISSION REDUCTIONS, PERCENT		
	A	B	C	D	E	HC	CO	NO
ENGINE PARAMETER INSPECTION								
1. IDLE (FRANCHISED)	950	420	5145	4.00	4.50	2.4	2.6	-0.2
2. EXTENSIVE A+ (FRANCHISED)	1780	645	1020	11.30	22.40	10.8	2.6	-0.2
3. EXTENSIVE B++ (FRANCHISED)	1975	695	1070	24.80	29.20	11.6	5.1	-1.1
EXHAUST EMISSION INSPECTION								
4. IDLE (STATE LANE)	730	340	∞	3.20	4.10	1.5	2.9	-0.0
5. EXTENSIVE A+ (STATE LANE)	1305	470	915	10.10	17.50	7.9	2.9	-0.0
6. EXTENSIVE B++ (STATE LANE)	1475	510	1045	12.35	21.35	8.1	3.4	-0.3

+ IDLE PLUS IGNITION TUNEUP, WITH DYNAMOMETER

++IDLE PLUS IGNITION PLUS INDUCTION TUNEUP WITH DYNAMOMETER

+++L. A. BASIN WEIGHTING FUNCTION

A. Computed over five year period.

B. Computed at end of last interval.

C. Based on statistically significant emissions reductions for last interval.

D. Based on total vehicle population.

E. Based on maintained portion of vehicle population.

The smaller incremental emission reductions effected with the emission inspection procedure followed by the more extensive "B" maintenance result because of the relatively poor ability of this inspection procedure to detect component failures which affect induction system performance. Indeed, virtually all of the procedures investigated achieved only modest CO reductions and had no influence on NO_x. The largest CO reduction is achieved with a direct parameter inspection procedure and "B" maintenance. Average and fifth year CO reductions are 5.3% and 8.4%, respectively. The generally poor performance in reducing CO emissions is due in large part to poor garage performance in maintaining the induction system. The average maintenance effectiveness for the induction system repair is approximately 50% compared to 75% for the ignition system and 80% for the idle adjustment parameters.

Absolute values for emission reductions instead of percent emission reductions can be used as the criteria for evaluating the performance of alternate inspection and maintenance procedures. Table 3-9 presents the emission reductions in tons per day predicted by the computer model for the six basic inspection and maintenance procedures. These are the average emission reductions achieved over a five-year program time span during which the automobile population grows from four million to over 4.6 million cars.

The population weighted, average emission profiles for the two basic inspection approaches are shown in Figures 3-5 and 3-6 for idle adjustment and extensive "B" maintenance programs, respectively. These profiles reveal slightly decreasing emission levels for HC and CO and nearly constant levels for CO with time. Two opposing effects are shaping these profiles--emission increases due to engine adjustment deterioration and emission decreases due to new vehicles having lower emission levels entering the population. As previously noted, all new vehicles entering the population are assumed to have emissions characteristics identical to the most advanced control system studies in this program (1971 California NO_x control). Therefore, the lowest possible emission values occur when the entire vehicle population is replaced with these vehicles and they are optimally maintained. At the end of the fifth year approximately 70 percent of the vehicle population are the equivalent of the 1970 NO_x controlled vehicles in varying states of deterioration.

TABLE 3-9

AVERAGE ABSOLUTE MASS EMISSION REDUCTIONS FOR SELECTED PROCEDURES

Inspection/Maintenance Procedure	Average Reductions+++		
	HC	CO	NO
		Tons/Day	
ENGINE PARAMETER INSPECTION			
1. Idle (Franchised)	19.6	255.	-0.99
2. Extensive A+ (Franchised)	87.2	255.	-0.91
3. Extensive B++ (Franchised)	94.3	520.	-5.37
EXHAUST EMISSION INSPECTION			
4. Idle (State Lane)	12.2	289.	-0.32
5. Extensive A+ (State Lane)	63.8	289.	-0.32
6. Extensive B++ (State Lane)	65.0	339.	-1.67

\+ Idle plus ignition with dynamometer.
++ Idle plus ignition and induction tuneup with dynamometer.
+++ Negative values indicate an actual increase over the baseline.

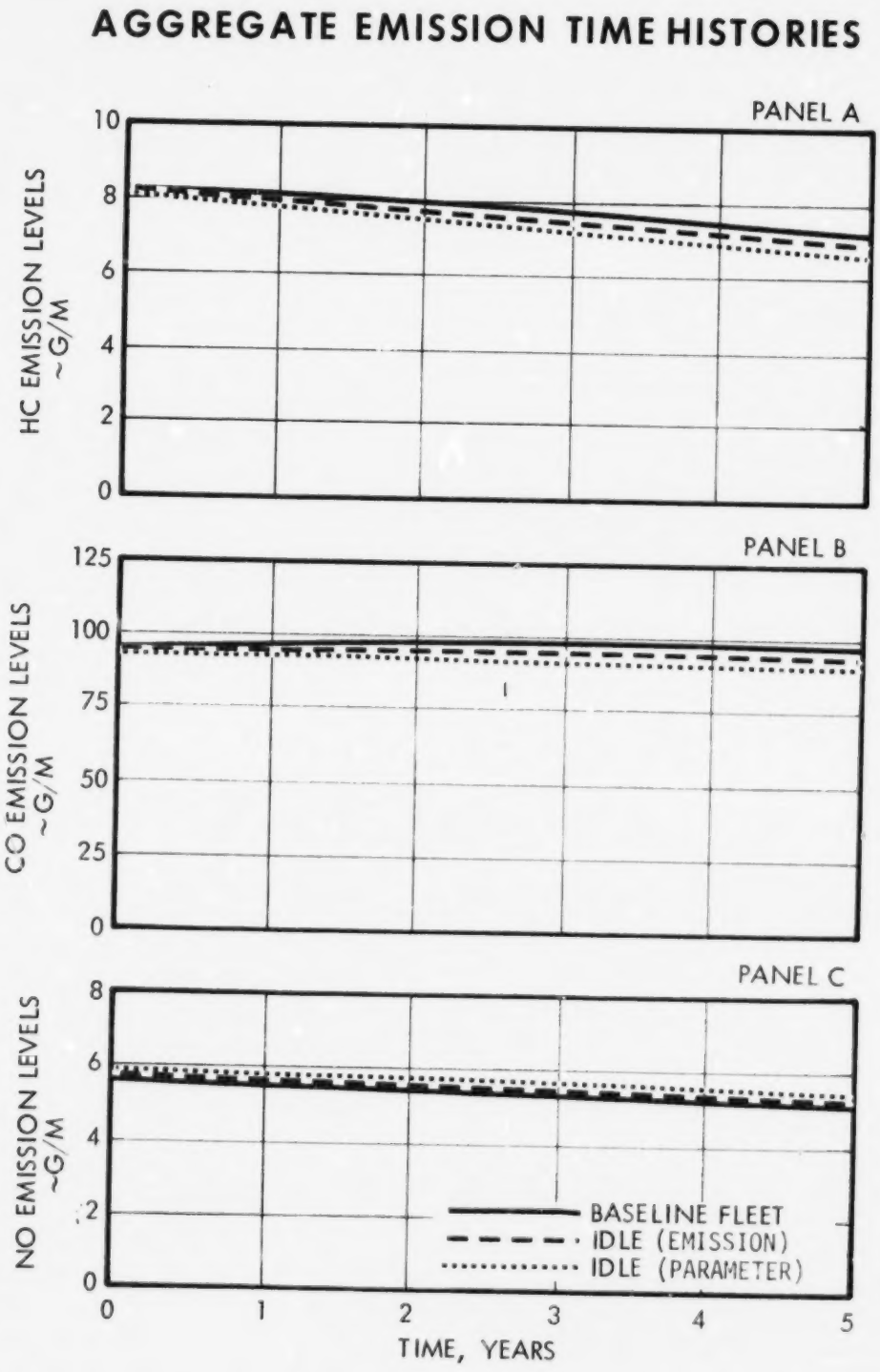


FIGURE 3-5 EMISSION TIME HISTORIES FOR IDLE MAINTENANCE TREATMENT

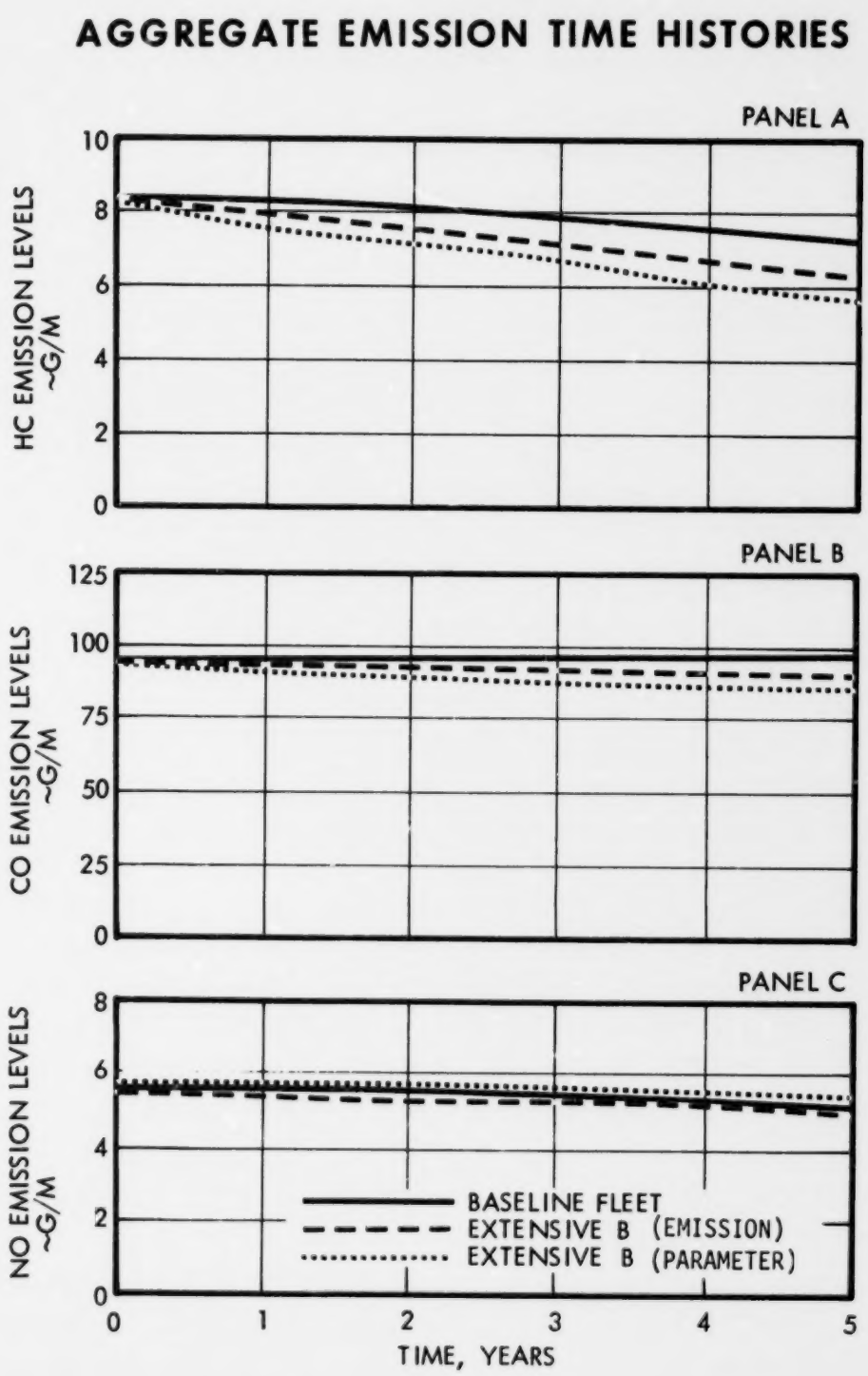


FIGURE 3-6 EMISSION TIME HISTORIES FOR EXTENSIVE B MAINTENANCE TREATMENT

The idle adjustment programs have their largest impact on the reduction of CO emissions and their smallest impact on NO_x. The resultant emission reductions relative to the baseline fleet have tended to stabilize by the end of the fifth year and are substantially larger than for the first several years of the program.

A similar trend in emission reductions with time can be seen for the more extensive inspection/maintenance programs. Greater HC and CO emission reductions are achieved by these procedures than by the idle inspection and maintenance programs. The HC and CO emission reductions appear stable relative to the baseline after four years. The larger HC emission reductions are attributable to the significant effect of correcting misfire by maintenance of the ignition system.

Figure 3-7 shows the rejection rate time histories for the nine engine maladjustments and malfunctions considered in the 1966-70 emission controlled vehicle fleet. Very little decrease in rejection fraction with time was found for some of the engine parameters while a substantial shift was found for ICO, timing and air cleaner restriction. This time sensitivity of the rejection fraction of individual engine parameters relates directly to the degree to which they are out-of-specification at program initiation, to their deterioration rates and to the effectiveness of maintenance. For example, a large percentage of vehicles have timing maladjustments most of which are corrected during the first inspection and maintenance cycle. Since timing adjustments deteriorate slowly subsequent inspections with a fixed pass/fail criterion find fewer malfunctions of this type. Over five years, the rejection fraction for timing was found to drop from 50% to less than 10%. For the more highly leveraged but infrequent malfunctions such as misfire, air pump failure, and NO_x control component malfunctions, a slowly decreasing rejection fraction occurs over the five-year program period.

A third characteristic deterioration profile is typified by a rapid decrease in rejection rate for several years followed by restabilization at about 50% of the initial value. A number of induction system parameters (PCV, idle speed, choke blade setting and heat riser valve) follow this trend.

FIGURE 3-7

ENGINE PARAMETER REJECTION TIME HISTORIES FOR AN EXTENSIVE B MAINTENANCE TREATMENT

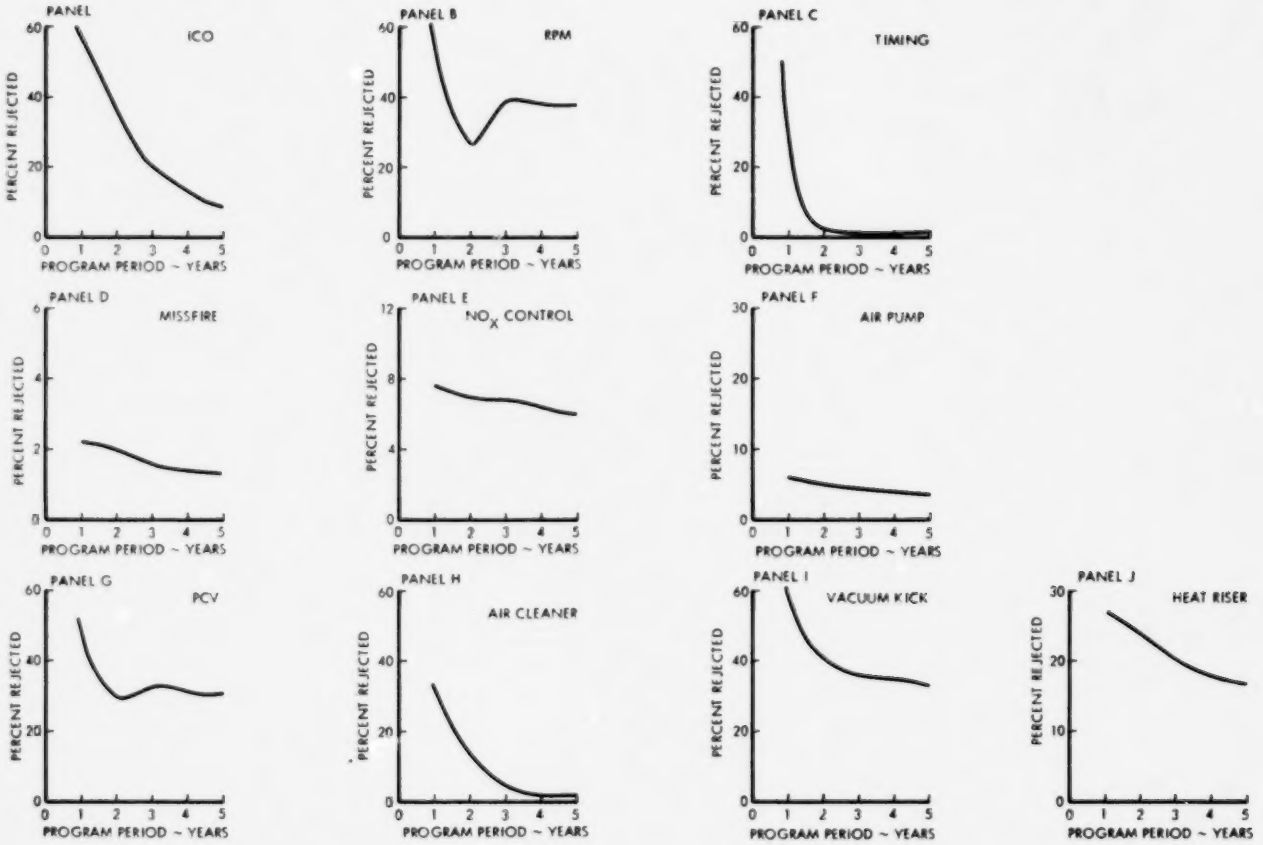
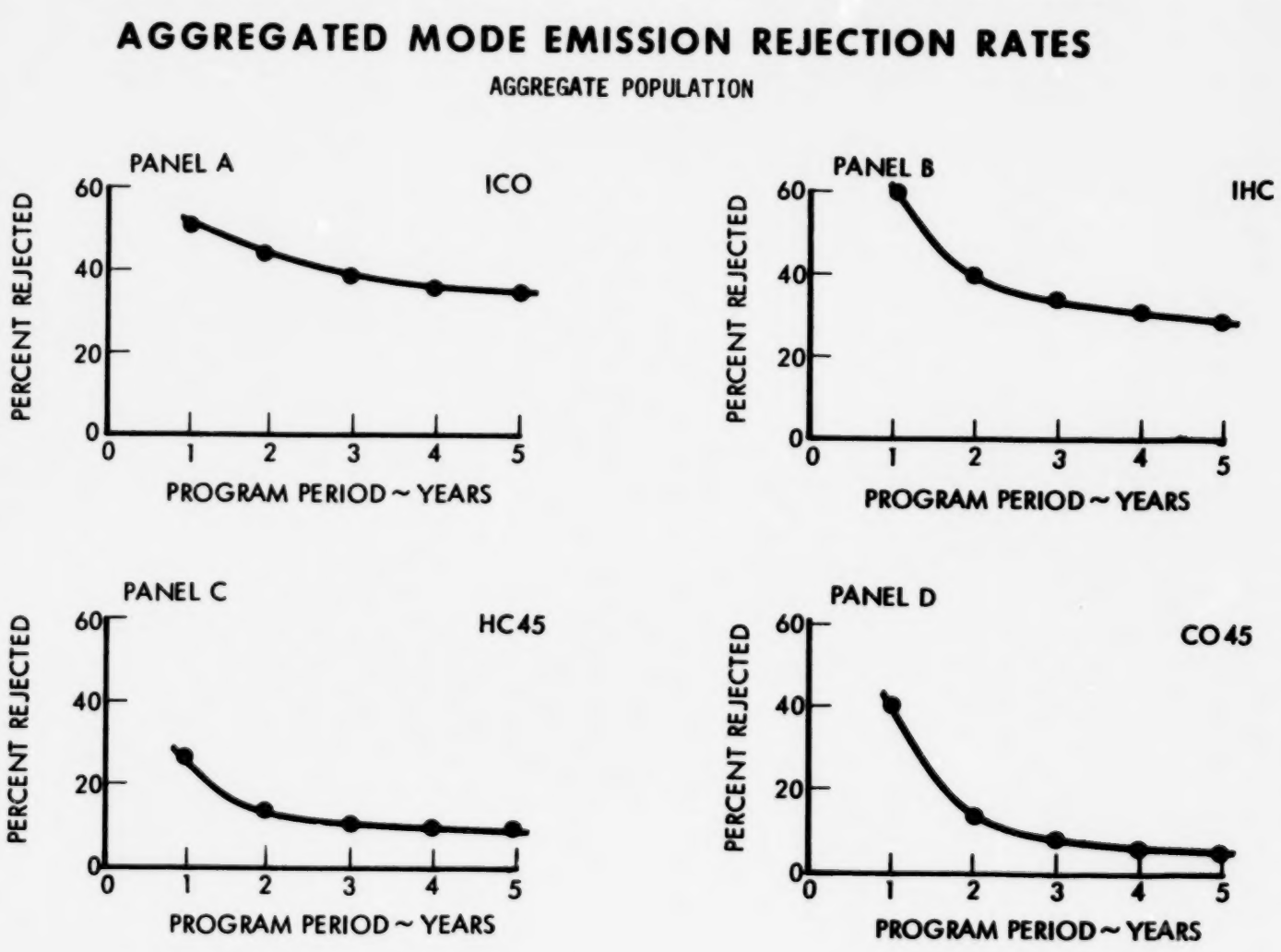


Figure 3-8 presents the population weighted fraction of vehicles rejected in an emission inspection by each separate idle or loaded mode measurement of CO and HC. The rejected fractions based upon idle CO measurements are relatively insensitive to program duration. This is because this mode is most sensitive to the idle fuel-to-air adjustment which deteriorates rapidly and not to the induction system malfunctions which have a longer deterioration profile. Although CO emissions measured under load identify only 10-40% of the induction system malfunctions of interest, sufficient failures are found and corrected in the first year to reduce 45 mph CO emission levels and, hence, rejection fractions in latter years.

Inspections using both idle and loaded mode HC emission levels result in a vehicle rejection level which decreases sharply with inspection program duration. This is because the first inspection finds most of the misfires within the general population with few errors of omission being committed. Since HC emission inspections in all test modes are nearly equally effective in detecting misfire, rejection rates using both idle and loaded modes are substantially reduced in later years. The remaining parameters affecting HC emissions (NO_x control and timing) are frequently malfunctioned and maladjusted, have low deterioration rates and/or are not adequately diagnosed with this procedure. The effectiveness of the emission inspection strategy can largely be attributed to the adequate diagnosis of idle fuel-to-air ratio maladjustment and misfire.

FIGURE 3-8

MODE EMISSION REJECTION TIME HISTORIES FOR AN EXTENSIVE B MAINTENANCE TREATMENT



The engine parameters and mode emissions selected for use in a mandatory vehicle inspection and maintenance program by the Economic Effectiveness Model and the inspection failure criteria for each are summarized in Table 3-10. The engine parameter pass/fail criteria are given relative to their specification or nominal values. The engine parameters selected by the model are idle CO, misfire, PCV valve and air cleaner for all three vehicles fleets. For controlled vehicles prior to 1971 the idle adjustments of rpm and timing are also cost-effective to maintain. It is again emphasized that this selection is based upon minimizing a figure of merit which incorporates specific weighting factors on emission reductions. A different figure of merit incorporating other emissions weighting factors may result in selecting other procedures.

A sensitivity analysis of the foregoing results revealed that the following factors bear on the selection of an inspection and maintenance policy:

- Imperfect maintenance is a major source of degradation in economic effectiveness.
- Uncertainities in deterioration rates can have a major influence on the figure of merit.
- CO emission reduction is very sensitive to a mandatory maintenance program, whereas NO_x emission is only slightly affected.
- A program of voluntary maintenance, assuming improved reliability of repair, is a viable alternative to mandatory maintenance.
- The effectiveness of the mandatory program is highly sensitive to the weighting factors assigned to the reduction of the various exhaust species.
- The figure of merit is relatively insensitive to labor costs.

TABLE 3-10

OPTIMAL PASS/FAIL CRITERIA FOR LOS ANGELES

PARAMETERS/MODE EMISSIONS		OPTIMAL SYSTEM PASS/FAIL CRITERIA*					
		PRECONTROLLED		CONTROLLED		POST 1970	
		PARAMETER DELTA	MODE EMISSION	PARAMETER DELTA	MODE EMISSION	PARAMETER DELTA	MODE EMISSION
• IDLE							
• IDLE CO (%)	• IDLE CO (%)	0.05	5.9	0.05	3.8	0.04	3.2
• RPM		----		5.00		----	
• TIMING (DEG)	• IDLE HC (PPM)	----	--	0.05	250.0	----	--
• IGNITION							
• MISFIRE (%)	• CRUISE 45 HC (PPM)	2.50	450.0	2.50	250.0	2.50	200.0
• NO_x		___		___		----	
• INDUCTION							
• AIR PUMP		___		----		___	
• PCV (CFPM)		-0.02		-0.03		-0.01	
• AIR CLEANER (DEG)	• CRUISE 45 CO (%)	30.00	3.5	25.00	1.5	10.00	1.0
• CHOKE VACUUM KICK (IN.)		----		----		----	
• CHOKE HEAT RISER		----		----		----	

Key: ___ Vehicle not equipped

---- Parameter not inspected

-- Mode emission not inspected

* As measured from manufacturers spec.

4.0 STUDY CONCLUSIONS

Conclusions derived from the study of two classes of inspection procedures and several maintenance treatments are described below. For convenience, the conclusions are categorized into four major segments: test results, procedure selection, system sensitivity analysis and regional implications. These conclusions are based on preliminary experimental data. The study results will be revised and upgraded using forthcoming experimental data in a final report at the conclusion of the program.

4.1 TEST PROGRAM

A number of conclusions were drawn directly from the test program results:

- The diagnostic content of emission modes are as follows:
  - CO and HC emissions in loaded engine operating modes are influenced by induction components that affect fuel-to-air ratio.
  - Advanced timing increases NO_x emissions under loaded engine modes and increases HC emissions at idle.
  - Idle HC emission measurements are weakly affected by idle RPM.
  - Combined idle HC and CO emission measurements are affected by the idle mixture ratio.
- Significant emission increases were observed in the first two vehicle recall periods of the deterioration tests, but could not be systematically related to corresponding changes in engine settings. This test program is continuing.
- The performance of service organizations in correcting emission related malfunctions and maladjustments was marginal at best, even when attention was drawn to specific maladjustments.
- Unnecessary repairs can be expected to occur. The absolute magnitude of the costs incurred is uncertain based on the data available from this program, but can run from 10-30% of the repair bill.

4.2 INSPECTION AND MAINTENANCE PROCEDURES

The conclusions derived from this study are generally similar to those given in the Interim Report. This analysis differs from the previous one in the following regards:

- o The entire vehicle population is considered, i.e., uncontrolled vehicles, pre 1971 controlled vehicles and post 1971 controlled vehicles.
- o Experimental data on the reliability of repair and maintenance durability is used for the first time.
- o The results are based upon the 1972 Federal Emission Test Procedure.

The results of the optimization for three levels of maintenance and the two inspection strategies are discussed below. These optimizations use a system figure of merit defined as the total annularized-discounted system costs per weighted ton of emissions reduced. Emissions weighting factors of 0.6, 0.3 and 0.1 were applied for HC, NO_x and CO, respectively.

- The results obtained using the new experimental data indicate a degradation in program performance when contrasted with the interim report results. This situation can be attributed primarily to three factors: 1) lower emission deterioration rates, 2) lower garage maintenance effectiveness and 3) higher program costs.
- The most cost-effective inspection/maintenance procedure (figure of merit of 475) is an idle emission inspection in a state lane followed by adjustment of idle CO, idle speed and timing. Five-year average HC, CO and NO emission reductions are 1.5, 2.9 and 0%, respectively.
- The most practical inspection/maintenance procedure (figure of merit of 1305) employs an idle mode HC and CO and loaded mode HC emission inspection in a state lane followed by the adjustment of the idle parameters and the repair of ignition system components causing misfire. Five-year average HC, CO and NO emission reductions of 7.9, 2.9 and 0% are achieved, respectively.
- The largest emission reductions are obtained with a direct engine parameter inspection followed as necessary by idle adjustments, ignition repair and repair of specified induction system components performed in franchised garages. This program is eight times more costly than the most cost-effective inspection/maintenance procedure.

- Emission inspection followed by idle adjustments and ignition system repair is also cost-effective when the statistically significant emission reductions at five years are used in the figure of merit in place of the predicted mean emission reductions.

- The most cost-effective parameters to maintain are the idle adjustments of CO, rpm and timing; the ignition system components causing misfire; and restricted air clearners and PCV valves.

- Fairly large inspection rejection fractions of between 40-60% are required to achieve reasonable emission reductions. This can be attributed in large part to the general ineffectiveness of garage maintenance.

4.3 SYSTEM SENSITIVITY ANALYSIS

Sensitivity studies were performed to determine the influence of the input data and assumptions on program performance. The previously discussed conclusions were generally found to be insensitive to these data and assumptions with respect to selection of the optimum procedures. The procedures performance values, however, are effected and in general were found to be sensitive to:

- The effectiveness with which repair is made by a service organization. For example, if repair reliability were perfect, larger HC emission reductions and particularly larger CO emission reductions could be obtained.

- The estimated rate of engine parameter deterioration, particularly idle fuel-to-air ratio and misfire.

- The extent of voluntary maintenance as it is currently modeled. Obviously, as vehicles are better maintained voluntarily, a mandatory program becomes less attractive.

- The weighting factors assigned to the reduction of each emission specie, particularly when CO reductions are weighted heavily.

- The frequency of imposed inspection and maintenance. Once yearly appears optimal.

- Direct program costs such as maintenance, labor and user inconvenience as well as the cost of unnecessary maintenance.

4.4 REGIONAL IMPLICATIONS OF VEHICLE INSPECTION/MAINTENANCE

Two hypothetical regions were modeled having different air quality problems and vehicle populations. The economic-effectiveness of mandatory inspection and maintenance is most influenced by the emission reduction weighting factors assigned to various regions. Weighting factors which stress CO reduction generally result in a program that does little to control HC and NO emissions. However, large absolute reductions of CO occur, thereby resulting in an extremely good figure of merit. Those procedures which involve adjusting idle fuel-to-air ratio to specification are most effective for controlling CO emissions. CO emission reductions can be approximately doubled by maintaining components of the induction system but at four times the cost. Even larger improvements can be achieved if induction system maintenance effectiveness is improved.

In regions where photochemical smog is a problem and HC and NO_x emission reductions are heavily weighted, timing adjustments and ignition system repair become important. Little reduction of CO emissions is desired since NO_x emissions are adversely affected.

These regional results clearly indicate the requirement for a "customized" program designed to meet a specific air pollution problem. The arbitrary application of a program developed for one region to a region with differing air quality and demographic characteristics could yield counterproductive results.